CHARACTERIZATION OF FOUR-TERMINAL-PAIR RESISTANCE STANDARDS: A COMPARISON OF MEASUREMENTS AND THEORY

R. E. Elmquist, A. Jeffery, and D. G. Jarrett
National Institute of Standards and Technology*
Gaithersburg, MD, 20899-8112 USA

Abstract

Coaxial straight-wire resistance standards with calculable frequency dependence have been used to tie alternating-current (ac) measurements to direct-current (dc) measurements of resistance. Coaxial standards of values 100 Ω and 1000 Ω are compared with each other and with other resistance standards at several frequencies up to 15 920 Hz using ac bridges.

Introduction

Since its introduction in the 1960s, the four-terminal-pair definition [1] has been used in ac bridge impedance measurements to eliminate or reduce uncertainties due to contact impedance and shunt admittance. Techniques for comparing four-terminal-pair admittance standards were developed and investigated [2] by Cutkosky, using ac bridges which allow measurement uncertainties of one part in 10^8.

The type of standards measured in these bridges can be represented by the circuit of Fig. 1. Coaxial chokes on measurement leads ensure that the net currents in the leads are zero. The bridges are adjusted to eliminate any current in lead 2 (potential) and lead 4 (zero detector) and "defining transformers" are used on connecting leads 2 to detect any current and 3 (current out) to inject an ac voltage. Each lead is a terminal pair consisting of an inner conductor and outer conducting shield. In the four-terminal-pair definition the admittance of certain leads and of roughly one-half of each defining transformer becomes part of the measured admittance of the standard. This means that in certain ranges of admittance and frequency, a general four-terminal-pair network with leads as shown in Fig. 2 should be considered [1].

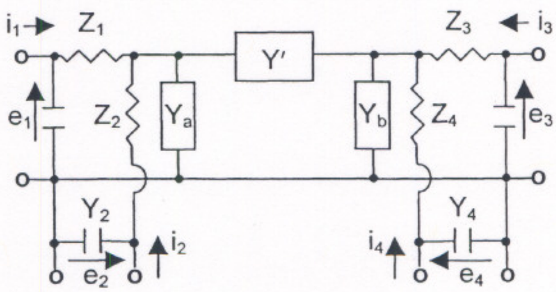

Fig. 1. A four-terminal-pair admittance for a coaxial resistor represented by an equivalent circuit, with Y′ as the series admittance of the main element, Y_a and Y_b as the shunt admittances of the coaxial elements, and Y_x and Z_x representing other impedances and admittances.

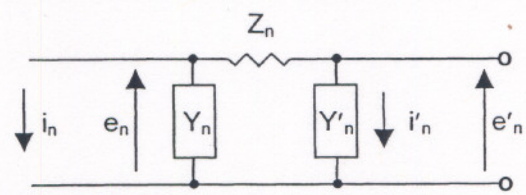

Fig. 2. More general equivalent circuit representation of a four-terminal-pair network lead.

Calculable Ac Resistors

Coaxial straight-wire resistors of the four-terminal-pair construction, with a calculable frequency response, were described in 1969 by Haddad [3]. The calculations are based on physical properties of the resistance wire, of the mounting and shielding conductors, and on expected deviations from the ideal coaxial design. One such 1000 Ω resistor has been in use at NIST since 1969. A similar 100 Ω coaxial resistor was also built and was used to check the frequency-response model with measurements made on a 10:1 ratio ac bridge. Phase-angle standards have been used for absolute measurements of the phase-angle of the 1000 Ω coaxial resistor. Both relative and absolute preliminary measurements have agreed to within about one part in 10^8 with the predictions of the model.

NIST has used similar designs to construct one new 100 Ω and three new 1000 Ω coaxial resistors. Heat-treatment of the resistance element has improved the

* Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce. Official contribution of the National Institute of Standards and Technology, not subject to copyright in the United States.

drift and temperature coefficients of the new standards over that of the earlier 1000 Ω standard. Some changes in the design [4] reduce the effect of frequency by reducing the skin effect in the mounting rods. The resistance wire in one of the new 1000 Ω standards is supported inside a thick-walled glass capillary tube. Another of the new coaxial 1000 Ω resistors has resistance wire of different diameter and length. The dc and ac behavior of these resistors has been characterized by several bridges, and the results of these and further measurements will be described in the full conference paper.

As an aside, note that several types of calculable ac resistors have been developed elsewhere. For resistance values higher than about 1000 Ω, special calculable resistors with quadrifilar or octofilar resistance elements have been in use at several national laboratories in recent years. At frequencies higher than about 100 kHz, a coaxial metallic film-type resistance element [5,6] has been developed that could reduce the effects of inductance and the skin effect below that of the fine wire used in these coaxial resistance standards.

Measurements

Most or all of the measurements described in this paper will employ one of two four-terminal-pair ac bridges [2]. The first bridge is a direct-reading ratio set (DRRS) that allows comparisons of admittance standards whose ratio is nominally 10:1. This has been used to compare each of the four NIST-built 1000 Ω coaxial standards to the new 100 Ω coaxial resistor at two frequencies. The effects of the leads are quite large in this measurement and will be a subject of investigation. The DRRS also will be used to compare a stable, conventional 10 kΩ standard resistor against the four 1000 Ω coaxial standards.

The second bridge is a 100:1 ratio equal-power resistance bridge. Preliminary measurements have been described [4], comparing the Haddad 1000 Ω resistor to one of the new 1000 Ω resistors by the substitution method, using 100 kΩ resistors of known phase-angle [7] as reference standards. We plan to continue these measurements with each of the four 1000 Ω coaxial standards.

Conclusion

Measurements are underway to characterize NIST coaxial resistance standards for use as ac-dc transfer devices at audio frequencies. The expected ac-dc shift of the standards is less than one part in 10^9 at 1592 Hz for the 1000 Ω resistance standards. We will present the results of ac bridge measurements and a reasonable estimate of the uncertainty in the measured frequency dependence.

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